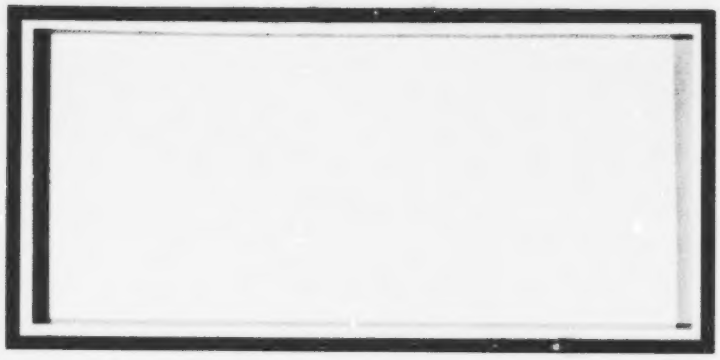

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Fracture Resistance Characterization of Canadian Steels

ADDENDUM TO FINAL REPORT

BY

ONTARIO RESEARCH FOUNDATION

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada.

DSS FILE NUMBER : 26SQ.23440-4-9113
DSS CONTRACT SERIAL NUMBER : OSQ84-00117
CANMET PROJECT NUMBER : 425251
CANMET SCIENTIFIC AUTHORITY : K.C. WANG

23rd October, 1984

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SUMMARY

Dynamic fracture testing is an essential component of fracture control plans for engineering structures. In the previous investigation, instrumented Dynamic Tear testing was carried out on four grades of Canadian steels of two different plate thicknesses. In this investigation, Dynamic Tear testing was carried out on materials of the same thickness. The samples were produced by milling thick plates.

The steels responded differently to the removal of the surface material; for example, one grade of steel exhibited a large drop in fracture energy, while another grade showed no change. In all cases, the decrease in the fracture resistance could not be accounted for by the simple effects of reduced fracture area. The results appear to be closely related to the presence of a hard brittle skin material on some steels, which affects their crack initiation resistance mostly, but not the propagation resistance.

It is clear that the dynamic fracture characterization in terms of the total fracture energy alone is incomplete. Advanced fracture control plans must incorporate the resistance of a material to both crack initiation and propagation as well as the traditional total fracture energy.

1. INTRODUCTION

Fracture control plans for engineering structures require dynamic fracture resistance characterization of construction steels. One such criterion is "Dynamic Tear Energy of Metallic Materials" defined in ASTM E604-80. The steel plate materials evaluated and reported in the Final Report "Fracture Characterization of Canadian Steels" (DSS OSQ84-00117, CANMET Project No. 425251) consisted of two groups of plate thickness:

i) 19mm plate thickness
38 WT, 50 WT and 100 QT grades,

ii) 16mm plate thickness
70 WT grade.

The dynamic tear energy of all four grades were measured at full thickness and reported in the final report. It was decided to re-evaluate the dynamic tear characteristics of the three grades of thicker steel plates by reducing their thickness to that of the 70 WT grade steel plate, which is also the maximum thickness of specimens specified in ASTM E604-80.

This addendum report presents the test procedures, results and discussions of the effects of thinning on the dynamic fracture characteristics of 38 WT, 50 WT and 100 QT grades of steel plates.

2. MATERIALS AND PROCEDURES

The specimens for Dynamic Tear (DT) testing, in the longitudinal and transverse directions, were produced from the pieces remaining from the previous investigation [1]. DT testing was carried out on a Dynatup 8000 instrumented drop-weight machine. The output traces were used to calculate the total tear energy (E_t), and the crack initiation energy (E_i) which was taken at the peak load point on the load-time trace.

The quantity, $E_t - E_i$, was designated as E_p, the crack propagation energy.

The test temperatures were 50, 22, 0, -46 and -80°C. A minimum of two specimens were tested at each temperature, except at -80°C. At this temperature, all the steels exhibited consistently low values of fracture energy, and therefore, there was little need to duplicate the test. The remaining specimens were used to supplement data at other test temperatures where the scatter in the fracture energy was greater.

3. RESULTS AND DISCUSSION

The numerical DT energy results for the 38 WT, 50 WT and 100 QT grades of steel plates are summarized in Tables 1, 2 and 3 respectively, for the longitudinal direction (A) and for the transverse direction (B). The averaged DT energy values are plotted against the respective test temperatures in Figures 1 and 2, respectively, for the longitudinal and transverse directions. The results for 70 WT obtained during the previous investigation are shown on the same plot.

The removal of the skin material appears to have resulted in drastic lowering of the total fracture energy of the 50 WT grade steel in the ductile fracture range. The effect was less severe on the 38 WT grade steel and it was virtually absent in the 100 QT grade steel. Such drastic effects of the surface material on the fracture resistance behaviour of different materials, warrant further examination.

50 WT Grade

It is evident, by comparing the values of E_i and E_p for the longitudinal direction in Table 11 (A) in the Final Report and Table 2 (A), that the drop in the fracture resistance is due almost entirely to the drop in the values of E_i. For the transverse specimens, the E_i values are higher for the 16 mm specimens than for the 19 mm specimens. These results are indicative of a significant role played by the skin material in affecting the fracture initiation behaviour in certain types of materials.

While the above observation indicates that the rapid drop in the fracture resistance (in the temperature range 50 to 0°C) was brought about by a reduction in the crack initiation resistance, the propagation energy does not appear to be affected greatly by the surface removal. The reduction in the fracture energy in this case is roughly consistent with the geometrical reduction in the fracture area.

Based on the analysis of the E_i/E_p ratios at various temperatures, it was suggested in the previous report that the 50 WT material was the most brittle of the four materials tested. The E_i/E_p data from this investigation provide further supporting evidence, and the overall data suggest that the brittle nature of this material may be related to the surface microstructures produced during its fabrication process.

The removal of this skin material appears to have an effect of shifting the onset of brittle fracture from around room temperature for the 19 mm material to around 0°C (or less) for the 16 mm material.

100 QT

The total fracture energy of this material in either the longitudinal or transverse direction was hardly affected by the thinning. The E_i values remained largely unaffected at all test temperatures except at 50°C, where the E_i values were higher in the 16 mm longitudinal specimens. The E_p values were lower in the thinner specimens in accord with the reduced fracture area, but their temperature dependence was altered by the surface removal.

For the 19 mm thickness material, the E_i/E_p analysis showed the dominance of E_i over E_p to begin at around -45°C, while in the 16mm thickness material the corresponding temperature appears to be around -80°C. This observation again confirms the detrimental effect of the (hard) surface material on the fracture behaviour of this type of steel.

The increase in the propagation resistance of the 16 mm thick specimens over the 19 mm thick specimens at -45°C is illustrated in Figures 3 (A) and (B), respectively. The increase in the area under the curve (E_p) for the 16 mm specimen is obvious without resorting to calculations.

38 WT

The overall effect of removing the surface material, on the fracture behaviour is generally the same as that for the 50 WT material. It is most evident in the ductile temperature range, and the reduction in the fracture energy is almost entirely borne by the E_i. As with other materials, the E_i values in the transverse specimens are higher in the 16 mm than in the 19 mm specimens. There is some indication that the thinner specimens remain ductile to lower temperatures, in consistent agreement with the behaviour of 50 WT and 100 WT specimens, but this effect is not very pronounced.

4. CONCLUSIONS

1. The dynamic tear energy was effected by the removal of the surface material to reduce the thickness of mill-produced plate materials.

2. The general effect of surface material removal on the fracture energy is to decrease the fracture resistance of the material in the ductile fracture range. This decrease is more than can be accounted for by the reduction in the fracture area.

3. The degree to which a material is affected by the surface material removal appears to vary from steel to steel, probably because of the microstructural inhomogeneity, produced by different manufacturing histories, at the surface and in bulk regions.

4. The 50 WT grade steel was most severely affected by the thinning action, and the decrease in fracture energy was almost entirely due to the reduction in the crack initiation energy (E_i) while the propagation energy (E_p) was hardly affected.

   The analysis of E_i/E_p presented in the Final Report indicated that this material was the most susceptible to brittle fracture.

5. This investigation suggests that the susceptibility of 50 WT to brittle fracture may be related to the presence of a hard and brittle skin material, which produces a high stiffness in the room temperature region but becomes brittle at lower temperatures.

6. In contrast, the fracture energy of the 100 QT grade steel was virtually unaffected by thinning. This behaviour is consistent with the expected homogeneous microstructure of this material. However, even in this material there may be some effect of the surface material, judging from the observed increase in the propagation energy of the thinned specimen at 45°C, as compared with the as-received specimen.

7. This investigation demonstrated that the fracture resistance of steels cannot be interpreted simply in terms of the total fracture energy alone. The effects of metallurgical and process variables on each of crack initiation and propagation processes must be recognized.

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Research Scientist,
Materials Division.

REFERENCES

(1) H. Shimizu and W.M. Gibbon "Fracture Resistance Characterization of Canadian Steels" Final Report, DSS File No. 26SQ.23440-4-9113 CANMET Project No. 425251, August, 1983.

TABLE 1.

DYNAMIC TEAR TESTING OF 38WT

(A) LONGITUDINAL DIRECTION

Specimen No.	Test Temp. (°C)	E_i (J)	E_p (J)	E_t (J)
L1	50	252	465	717
L2	50	260	554	814
L3	50	284	623	907
L4	22	509	441	949
L5	22	433	567	999
L7	0	106	145	251
L8	0	106	159	265
L9	0	106	184	290
L10	-45	18	13	31
L11	-45	19	19	38
L12	-45	19	21	40
L13	-78	14	7	21

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

TABLE 1.

DYNAMIC TEAR TESTING OF 38WT

(B) TRANSVERSE DIRECTION

Specimen No.	Test Temp. (°C)	E_i (J)	E_p (J)	E_t (J)
T1	50	433	845	1277
T2	50	420	848	1268
T3	50	471	796	1267
T4	22	160	410	570
T5	22	420	273	693
T6	22	414	464	877
T7	0	108	236	343
T8	0	220	237	457
T9	-46	20	13	34
T10	-46	18	12	30
T11	-78	14	4	18

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

TABLE 2.

DYNAMIC TEAR TESTING OF 50WT

(A) LONGITUDINAL DIRECTION

Specimen No.	Test Temp. (°C)	E_i (J)	E_p (J)	E_t (J)
L1	50	81	1144	1125
L2	50	54	1279	1333
L3	50	54	1279	1333
L4	22	174	803	976
L5	22	187	949	1136
L6	22	174	734	907
L7	0	199	370	570
L8	0	239	428	667
L9	0	239	180	419
L10	-45	16	16	32
L11	-45	19	16	35
L12	-45	16	24	40
L13	-78	14	7	20

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

TABLE 2.

DYNAMIC TEAR TESTING OF 50WT

(B) TRANSVERSE DIRECTION

Specimen No.	Test Temp. (^{0}C)	E_i (J)	E_p (J)	E_t (J)
T1	50	343	793	1136
T2	50	343	815	1158
T3	50	357	644	1001
T4	22	266	317	583
T5	22	369	443	812
T6	22	343	374	717
T7	0	120	93	213
T8	0	213	181	394
T9	-45	38	27	65
T10	-45	24	11	35
T11	-78	17	5	22

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

TABLE 3.

DYNAMIC TEAR TESTING OF 100QT

(A) LONGITUDINAL DIRECTION

Specimen No.	Test Temp. (°C)	E_i (J)	E_p (J)	E_t (J)
L1	50	407	717	1124
L2	50	420	716	1136
L3	50	471	664	1135
L4	22	192	964	1156
L5	22	187	697	884
L6	22	200	890	1090
L7	0	160	652	812
L8	0	160	700	860
L9	0	160	747	907
L10	-45	153	612	765
L11	-45	153	587	740
L12	-78	77	8	85

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

TABLE 3.

DYNAMIC TEAR TESTING OF 100QT

(B) TRANSVERSE DIRECTION

Specimen No.	Test Temp. (°C)	E_i (J)	E_p (J)	E_t (J)
T1	50	34	358	291
T2	50	41	251	291
T3	22	47	239	286
T4	22	41	270	310
T6	0	27	244	271
T7	0	81	210	291
T8	0	80	224	304
T9	-45	34	90	124
T10	-45	34	127	161
T11	-45	27	111	141
T12	-80	32	39	71
T13	-80	46	51	97

Where E_i = fracture initiation energy

E_p = fracture propagation, and

E_t = total energy

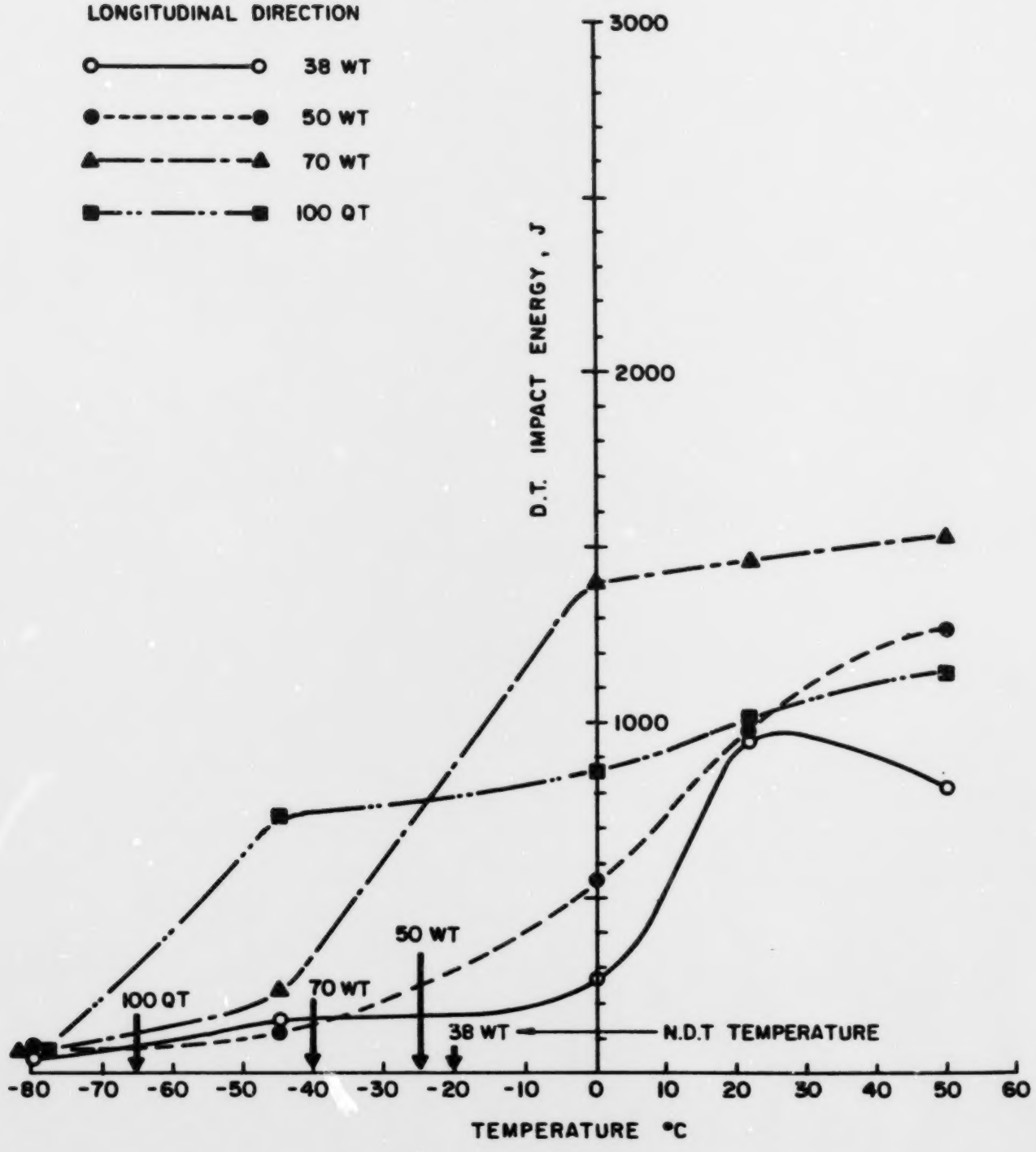


FIG: 1 : DYNAMIC TEAR ENERGY vs TEMPERATURE
LONGITUDINAL DIRECTION

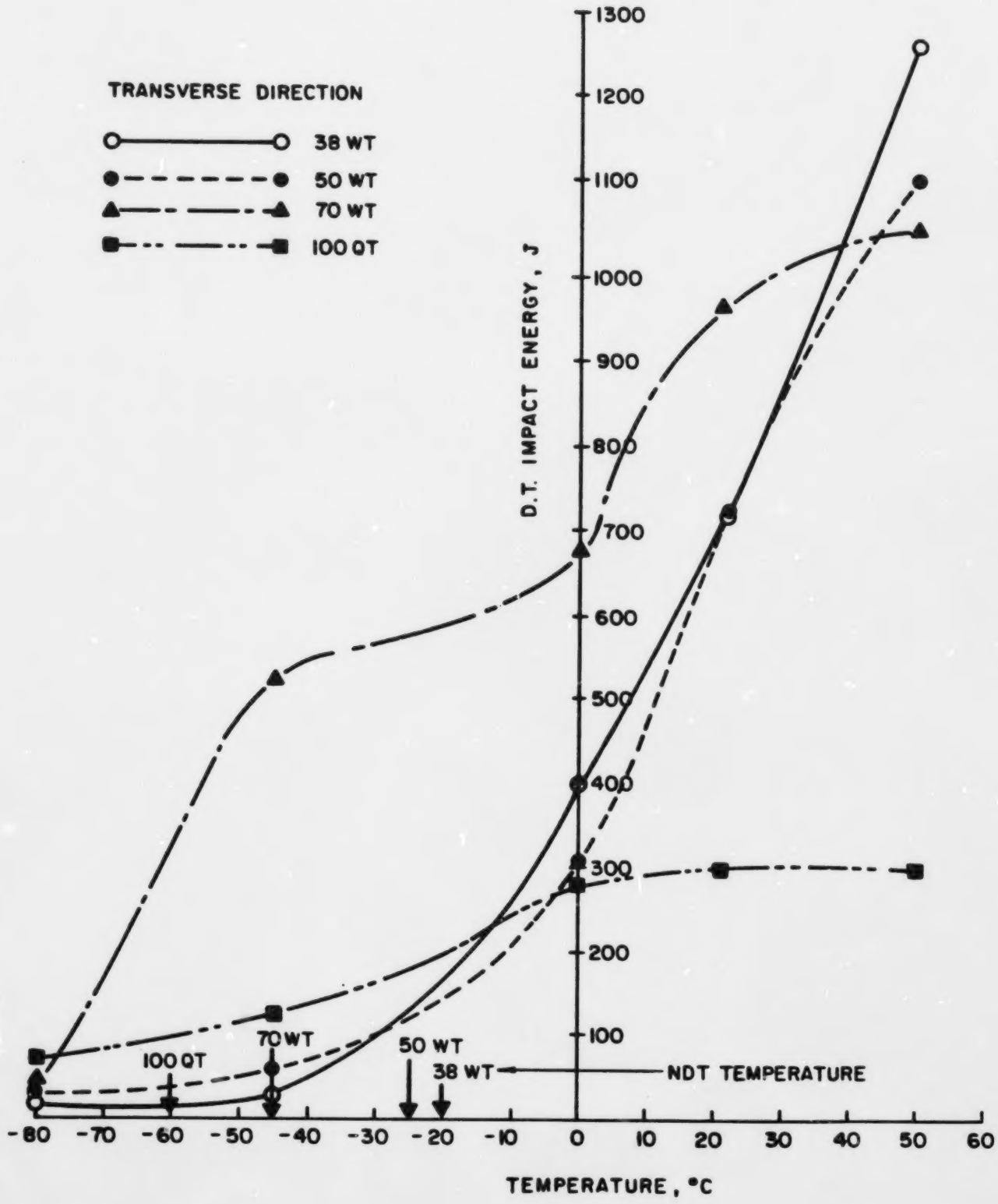


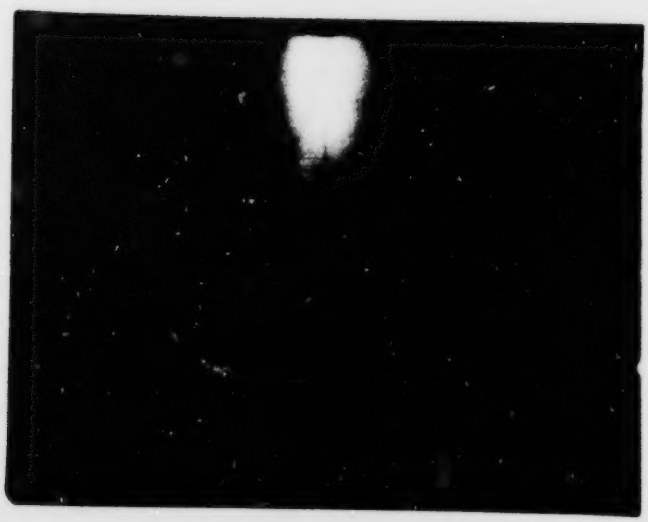
FIG 2 : DYNAMIC TEAR ENERGY vs TEMPERATURE
TRANSVERSE DIRECTION.

(A) 16 mm thickness

Material : 100 QT

Longitudinal Direction

Temperature : -45°C
Force : 4.45 KN/div.
Time : .5 ms/div.
Energy: 136J/div.



(B) 19 mm thickness

Figure 3: Comparison of fracture behaviour.

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